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Final report on the weldability of heat-resisting

Alloys (N-102)

Feild, A.L.; Bloom, F. K.; Linnert, G. E.;

OSRD, NDRC, Div. 18, Washington, D. C.

OSRD-6329

Materials (8) Testing (16)

18400

Feild, A. L.
Bloom, F. K.
Linnert, G. E.

Materials (8)
General Data (15)
High temperature alloys (49326);
Alloys - Welding (10302)

O.S.R.D.- 6329

Final report on the weldability of heat-resisting alloys (M-102)

O.S.R.D., N.D.R.C., Div.18, Washington, D. C.

U.S. Eng. Restr. Dec'45 58 28 photos, tables, drwgs

Study was made of the welding characteristics of heat-resisting alloys employed in turbosuperchargers, jet engines, and gas turbine wheels. Welds in five wrought alloys and two cast materials were subjected to the bead-on-plate test, restrained butt-joint test, and a special wheel-and-bucket type of test. Three types of cracking found to be prevalent were weld metal cracking, heat-affected-zone cracking, and cracks propagating from interbucket junctions. In general, Hastelloy "B" and Timken 16-25-6 alloys appeared to be the least susceptible to welding defects.

Project- N-102

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NATIONAL DEFENSE RESEARCH COMMITTEE

of

O.S.R.D. # 6389

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

WAR METALLURGY DIVISION

Final Report

on

THE WELDABILITY OF HEAT-RESISTING ALLOYS (N-102)

by

A. L. FEILD, F. K. BLOOM, AND C. E. LINNERT
RUSTLESS IRON AND STEEL CORPORATION

OSRD No. 6389

Serial No. M-626

Copy No. 41

December 5, 1945

December 5, 1945

To: Dr. James B. Conant, Chairman
National Defense Research Committee of the
Office of Scientific Research and Development

From: War Metallurgy Division (Div. 18), NDRC

Subject: Final Report on "Weldability of Heat-resisting Alloys (W-102)"

The attached final report submitted by A. L. Feild, Technical Representative on NDRC Research Project NRC-90, has been approved by representatives of the War Metallurgy Committee in charge of the work.

This report presents the results of an investigation of the welding characteristics of various heat-resistant alloys employed in turbo-superchargers, jet engines, and gas turbine wheels.

These investigations are being continued by the Rustless Iron and Steel Corporation, as a phase of a comprehensive research program on heat-resistant alloys being conducted by Battelle Memorial Institute under a direct contract with the Office of Research and Inventions, Navy Department.

I recommend acceptance as a satisfactory final report on the work done under Contract OEMsr-1466 with Rustless Iron and Steel Corporation.

Respectfully submitted,

Clyde Williams

Clyde Williams, Chief
War Metallurgy Division, NDRC

Enclosure

PREFACE

This report is pertinent to the problems designated by the Navy Department as N-102, and to the project designated by the War Metallurgy Committee as NDRC Research Project NRC-90.

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FINAL REPORT

NDRC RESEARCH PROJECT, NRC-90

To The

WAR METALLURGY COMMITTEE

NATIONAL ACADEMY OF SCIENCES - NATIONAL RESEARCH COUNCIL

The Weldability of Heat Resisting Alloys

By

A. L. Feild, F. K. Bloom, and G. E. Linnert

From July 18, 1944 to October 31, 1945

October, 1945

Research Division

Rustless Iron and Steel Corporation

Baltimore, Maryland

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ACKNOWLEDGEMENTS

The work described in this report was conducted under the supervision of A. L. Feild in the Research Division of the Rustless Iron and Steel Corporation by F. K. Bloom and G. E. Linnert. Also collaborating were W. J. Dolan, W. H. Donoho, and H. O. Rodue, Jr. The metallographic examinations were made by M. Clegg, Jr. The chemical analyses were performed by W. F. Mulcoly.

R. W. Clark of the General Electric Company contributed much toward the development of the weld test specimens, H. C. Cross of the Battelle Memorial Institute assisted in selecting and procuring materials for testing, J. H. Humberstone of the Arcrods Corporation made arrangements for the radiographic examinations, and A. McKenzie of the Linde Air Products Company furnished assistance in installing and operating the submerged-melt welding equipment.

The cooperation of the personnel of the Allis Chalmers Manufacturing Company, Elliott Company, and General Electric Company, who were visited as fabricators, and the efforts of suppliers of heat resisting alloys in producing sample orders during a most difficult period of time, was greatly appreciated by the investigators.

The help of G. S. Mikhalapov, Supervisor of Welding Research, his two assistants, H. W. Hiemke and Dr. A. Muller, and each member of the Advisory Committee in guiding the course of the investigation was also greatly appreciated by the investigators.

* * * * * *

ABSTRACT

At the suggestion of the Advisory Committee of NDRC Project NRC-8, an investigation was undertaken to study the welding characteristics of heat resisting alloys employed in turbo-superchargers, jet engines, and gas turbine wheels. The primary objectives were the development of laboratory tests and procedures which would permit a comparison of the various alloys; to carry out this comparison on a series of selected materials; and to study the effect of variables in the welding procedure, particularly differences between the submerged-melt and manual-arc processes as well as the effect of preheat temperature.

Five wrought alloys and two cast materials were examined, Hastelloy "B", N155, Timken 16-25-6, Uniloy 19-9 DL, S816, cast Vitallium, and cast 6059. Three types of tests were employed, namely, bead-on-plate, restrained butt-joint, and a special wheel-and-bucket type test. Type 316 was used as weld filler metal throughout except in the case of N155 base metal where filler metal of the same composition was employed.

Since the project was terminated before the tests which had been planned could be completed, no final conclusions can be drawn. Enough work was done, however, to show that wide variations existed in the weldability of heat resisting alloys. Three types of cracking were found to be prevalent, namely, weld metal cracking, heat-affected-zone cracking, and cracks propagating from interbucket junctions.

In general, Hastelloy "B" and Timken 16-25-6 alloys appeared to be the least susceptible to welding defects. Alloys S816 and the two cast alloys were the most susceptible, and N155 and Uniloy 19-9 DL about intermediate. The cast alloys were particularly susceptible to cracking in the heat-affected-zone. The two wrought alloys containing substantial amounts of columbium were also susceptible to this defect. Weld metal cracking in deposits on cast materials often appeared as extensions of cracks in the heat-affected-zone. Weld metal cracking with the wrought materials was most severe when the weld deposits were entirely austenitic in character. The presence of delta ferrite appeared to inhibit this defect.

The wheel-and-bucket test which was developed, produced interbucket junction cracks similar to those occurring in production welding, and appeared suitable for the evaluation of different materials. The test confirmed the importance of weld deposit contour on interbucket junction cracking indicating that narrow straight-sided deposits were generally best. A few tests appeared to show that preheat to at least 600°F. tended to reduce this type of cracking.

FINAL REPORT

ON

THE WELDABILITY OF HEAT RESISTING ALLOYS

* * * *

INTRODUCTION

In June of 1944, the Advisory Committee of NDRC Project No. NRC-8 which deals with the development of heat resisting metals for gas turbine parts advised the War Metallurgy Committee that an acute need existed for information on the weldability of these materials. The Committee reported that a number of fabricators had called their attention to welding problems which were being experienced. One especially important application involved was the bladed rotor or impeller wheel used in aircraft turbo-superchargers - then being produced at a fever pitch. The Committee also foresaw a need for weldability data on newly developed heat resisting alloys. These materials had been evolved principally on the basis of mechanical properties at elevated temperatures, and little or nothing was known about their weldability. The Advisory Committee therefore suggested the organization of a welding test program.

Accordingly, the War Metallurgy Committee initiated the present investigation in July of 1944. It was planned to conduct the investigation by devising laboratory weld tests to study the types of defects reported to occur in turbo-supercharger wheels welded by both the manual-arc and submerged-melt processes. To utilize the time delay in securing equipment and materials to perform the work, an examination was made of a number of turbo-supercharger wheels submitted by one manufacturer. The results of this preliminary examination were only of limited importance.

In January of 1945, an Advisory Committee meeting was held to discuss the progress which had been made and review the aims and scope of the project. It was brought out at this meeting that because of recent developments, the need for investigative work on the welding of turbo-supercharger wheels had been surpassed by two other applications, namely, the jet propulsion unit for aircraft and the gas turbine for ships. In closing the meeting, the Committee suggested that the original plans of the investigation be altered so as to attain the following objectives.

(1) Develop a simple weld test, or tests, which would produce the defects encountered in welding heat resisting alloys by the submerged-melt or manual-arc processes.

(2) Test a series of selected alloys and determine their relative weldability.

(3) Include in the weld test if possible, the design features found in a bladed wheel so that data of immediate use to wheel manufacturers would also be obtained.

(4) Schedule the laboratory work to supply data for manufacturers of jet propulsion units first, of gas turbines second, and of turbo-superchargers third.

This alteration in plans did not cause any marked change in tactics because the three units, turbo-supercharger, jet propulsion engine, and gas turbine, were mutually related in a number of respects. The major welding problems in each case were involved in the bladed rotor or wheel. Also, a number of the selfsame alloys were under consideration as materials for wheel construction by the builders of each type unit. Although the wheels differed in size, they were all of similar design, especially from the standpoint of possessing a common design defect. In placing a complete ring of individual buckets around the center disk, the interbucket junctions constituted notch effect, or an incipient crack, at the edge of the weld metal.

In general, the bladed rotors or wheels could be classified into two types, "hot" wheels and "cold" wheels, according to their operating condition in service. A hot wheel operated with the entire section, that is, both the center disk and the outer ring of buckets, at an elevated temperature, perhaps 1000 to 1500°F. A cold wheel operated with only the buckets and a narrow outer peripheral section of the disk at an elevated temperature. The central portion of the disk remained relatively cold, perhaps from atmospheric temperature to 900°F.

The heat resisting alloys initially selected for weldability testing in this project are shown in the tabulation below. It was not practical to systematically classify and identify the materials according to their composition, and for this reason, their trade designations are used throughout the report. The tabulation has been separated into wrought alloys which may be used for disks or buckets and cast alloys which are used for buckets only, and includes the approximate composition of each.

	Cr	Ni	Co	Mo	W	Cb	Ti	Fe
Wrought Alloys								
Hastelloy "B"		70		30				Residual
N155	20	20	20	3	2	1		Balance
Timken 16-25-6	16	25		6				Balance
Uniloy 19-9 DL	19	9		1	1	.3	.3	Balance
S816	20	20	40	4	4	4		Residual
Cast Alloys								
Vitallium	28		Balance	6				Residual
6059	25	30	Balance	6				Residual

As the work progressed, several new alloys were added to this list, namely, wrought alloy S590, and cast alloys 422-19 and X40. However, the project was terminated before any tests could be conducted with these materials.

The electrode or filler metal composition first chosen for welding the alloys, with the exception of N155, was AISI Type 316. This grade was being widely used by fabricators with a fair degree of success and appeared to be the logical choice for the initial approach to evaluate weldability. It was planned that additional filler metal compositions would be selected or possibly even developed later in the project which would be better suited for welding particular alloys. Alloy N155 was to be welded with filler metal of the same composition.

In general, three types of weld joint defects were reported to occur in welded wheels. Listed and described in order of their relative importance, they were:

(1) Notch Extension - This is a form of cracking which initiated at the junctions between buckets on the outer edge of the weld metal and propagated radially across the weld joint. A typical example of notch extension in a turbo-supercharger wheel can be seen in Figure 1. Weld joints made by the submerged-melt process were reported to be more susceptible to this defect than joints made by the manual-arc process. The degree of susceptibility was also supposed to vary with the weld metal composition, which of course was determined by the three joint components, the wheel, bucket and weld filler metals. The defect presented a serious problem for the notch extensions continued to propagate when the wheel was placed in service and operated. Eventually they reached a size which endangered the strength of the wheel, at which point the wheel would be removed from service.

(2) Weld Metal Bead Cracking - Two forms of weld bead cracking were reported to occur. The first form was longitudinal cracking in the center of the deposited weld bead, generally in the first or root pass. The second form was scattered intergranular fissures ranging from microscopic size to large cracks readily visible to the naked eye.

(3) Underbead Cracking - Several instances of fusion zone cracking and "heat-affected-zone" cracking were reported to have occurred in the heavier section buckets of jet unit and gas turbine wheels. These materials were austenitic type alloys, and the presence of such defects is quite uncommon. However, the cracking appeared to be caused by "hot shortness" rather than a hardening and embrittlement.

In planning weld tests for the investigation it was imperative to have specimens which could be more readily and economically prepared than the usual bladed wheel.

The BEAD-ON-PLATE TEST was particularly attractive because of its extreme simplicity. This test was used at the start of the investigation as a preliminary test to secure some fundamental data on the alloys. The procedure merely consisted of depositing a bead on a piece of base material $\frac{3}{4}$" x $1\frac{1}{2}$" x 4" by submerged-melt or manual-arc welding and examining a transverse macro etched specimen and a metallographic specimen from the piece.

A RESTRAINED BUTT-JOINT TEST was first selected to represent the troublesome "bucket-to-wheel" weld joint. The test specimen consisted of two pieces of $\frac{3}{4}$" thick material forming a 70° single-V center butt-joint with abutting root faces. The pieces were clamped in a heavy jig during welding, and the root faces only partially fused leaving a notch in the weld joint. The purpose of this was to determine the susceptibility of the weld metal to notch extension. It was planned to prepare, a first series of such specimens using two base plates of only a single alloy, a second series in which the base plates would be of dissimilar compositions representing typical combinations of wheel and bucket alloys, and a third series similar to the second except a row of transverse segments would be substituted for the solid plate representing the bucket alloy. In addition to an examination of macro etch and metallographic specimens from these welded test plates, transverse tensile and face bend tests were also to be made.

Upon completion of the first series of restrained butt-joint tests using plates of only a single alloy, it was found that although the test furnished considerable information on the general weldability of the alloys, in no case did it disclose any appreciable extension of the root notch into the weld metal. Further tests would have been conducted substituting segments for the solid plate to secure additional notch effect, had it not been for the appearance of a new obstacle. Producers of cast alloys were experiencing considerable difficulty in making sound castings for the relatively large test specimens. Also, the grain size of the cast specimens was very much greater than that of the usual cast bucket. In view of the difficulty with unsoundness, and uncertainty on the influence of abnormally large grain size, it was decided to discontinue this test and redesign the specimen.

The WHEEL-AND-BUCKET DESIGN TEST was next developed as a weldability test. As the name indicates, the design of the specimen was similar to a bucketed wheel. However, instead of a center disk and a surrounding ring of buckets, the specimen consisted of a straight section to represent the wheel disk with a row of bucket-base replicas placed in butt-joint position. The assembly of pieces was clamped in a heavy jig and welded from both sides by either submerged-melt or manual-arc welding. A preheat temperature of 600°F. was used. This test design proved to be more successful than its predecessor in promoting interbucket notch extension into the weld metal.

At this stage of the investigation, a second meeting of the Advisory Committee was held to discuss the up-to-the-minute needs of fabricators for information on the weldability of heat resisting alloys. It appeared from the discussion at this meeting that the test data obtainable from the "wheel-and-bucket" specimen would suffice, but that the selection of alloys and combinations to be tested should be revised. A new program of future work was then drafted. Briefly, Timken wheel alloy, S816 bucket alloy and Type 316 filler metal were to be used as standard or control materials in studying the following:

(1) Influence of Preheat Temperature
(2) Weldability of Eight Bucket Alloys
(3) Weldability of Two Alloys for Cold Type Wheels
(4) Weldability of Three Alloy Combinations for Hot Type Wheels
(5) Weldability of Two Weld Filler Metals
(6) Weldability of Two Alloys for Both the Buckets and Wheels of Gas Turbines

Wheel-and-bucket tests were to be welded by both the submerged-melt and manual-arc processes, preferably in duplicate. The procedure for examining the specimens was to consist of (1) removing a discard portion from each end for macro etch testing, (2) grinding the top and bottom weld beads flush to measure interbucket notch extension, (3) radiographic examination, (4) metallographic examination of the notch extensions and any other defects revealed by the radiographs, and (5) microscopic examination of the fractured faces of the notch extensions.

Of the approximately eighty wheel-and-bucket tests planned, about one-third had been welded at the time the project was terminated. Examination of these tests had progressed to the point where all had been subjected to radiographic examination.

In addition to the investigative work dealing with the general weldability of heat resisting alloys, the Rustless Research Laboratory also collaborated with the U. S. Naval Engineering Experiment Station at Annapolis, Maryland in performing some preliminary high-temperature stress-rupture tests on joints in N155 alloy plate manually arc-welded with N155 electrodes. This work was conducted at the request of the Research Branch, Bureau of Ships, Navy Department, who had need for such data relative to the building of gas turbines from this alloy. The same base materials and welding electrodes as employed in the present weldability investigation were used in the work for the Bureau of Ships. However, because of the supplementary character of the work and the limited data available at this writing, no details are included in this report.

SUMMARY

Because this project was terminated before the tests which were planned could be completed, no attempt has been made to draw any final conclusions. Sufficient work was carried out, however, to permit certain significant observations which have been listed below. In some cases these observations are the result of only one or two tests and verification by additional test work is desirable.

(1) Enough work was done to show that wide variations exist in the susceptibility of different heat resisting alloys to the development of welding defects. Cracking of three types was found to be fairly prevalent, namely, cracks in the weld metal, cracks in the heat-affected-zone of the base metal, and cracks propagating from interbucket junctions. The seven materials examined exhibited the following approximate susceptibility to these defects:

Alloy	Weld Metal Cracking	Heat-Affected Zone Cracking	Interbucket Cracking
Hastelloy "B"	Very slight	None	Slight
Timken 16-25-6	Very slight	None	Very slight
N155	Moderate	Slight	Moderate
Uniloy 19-9 DL	Moderate	None	—
S816	Severe	Moderate	Severe
Vitallium	Severe	Severe	Moderate
6059	Severe	Severe	Moderate

In general, Hastelloy "B" and Timken 16-25-6 alloys appeared to be the least susceptible to welding defects. Alloy S816 and the two cast alloys were the most susceptible, and N155 and Uniloy 19-9 DL about intermediate.

(2) The cast alloys were particularly susceptible to cracking in the heat-affected-zone. These cracks occurred along the grain boundaries. While it was believed at first that the extremely coarse grain size of the large base metal pieces in the bead-on-plate and restrained butt-joint specimens had promoted this defect, the occurrence of the same defect in the smaller and finer grained bucket-type specimens failed to support this hypothesis and the reason for this susceptibility remains unexplained.

(3) Of the five wrought alloys examined, S816 and N155 were also susceptible to heat-affected-zone cracking. While the evidence secured to date is still very limited, it is believed that this cracking is due either to the melting of intergranular compounds formed in these alloys or to low ductility resulting from the presence of these compounds at the grain boundaries.

(4) Weld metal cracking was also pronounced in deposits on the cast materials. In many cases the weld metal cracks appeared as extensions of cracks formed in the heat-affected-zone of the base metal.

(5) Weld metal cracking which occurred with the wrought materials was most severe in cases where the base metal when alloyed with the filler metal resulted in weld deposits entirely austenitic in structure. Such alloys as Hastelloy "B" and Timken 16-25-6 which gave weld metal deposits containing delta ferrite as well as austenite appeared substantially free from this defect. The effect of small amounts of delta ferrite in austenitic weld deposits in inhibiting weld metal cracking has been previously established.*

(6) Limited mechanical tests on the welded specimens failed to disclose anything significant relative to their weldability. The data were really too few to warrant any conclusions.

(7) A successful laboratory test was developed which was capable of producing interbucket-junction cracks, similar to those occurring in the actual welding of turbo-supercharger wheels. In the limited time the test was employed it appeared that reasonably reproducible results could be secured and that the test should be suitable for the evaluation of the susceptibility of different materials to interbucket-junction cracking as well as to study the effect of various welding variables.

* Development of Armor Welding Electrodes (OD-36-2): The Effect of Variations in Chromium-Nickel Ratio and Molybdenum Content of Austenitic (20 Cr-10 Ni) Electrodes on Properties of Armor Weldments, by A. L. Feild, F. K. Bloom and G. E. Linnert. OSRD No. 3034, Serial No. M-182, December 14, 1943.

(8) In tests welded by the submerged-melt process, at least two variables were of importance. Namely, the composition of the weld metal and the contour of the weld deposit. Materials which appeared sensitive to interbucket-junction cracking, cracked severely when wide tapering deposits were made, but performed much better with narrow straight-sided deposits. With materials less susceptible to interbucket-junction cracking, deposit contour seemed to have little effect.

(9) A few tests were completed using the submerged-melt welding process to study the influence of preheat temperature. Over a range of temperature from 70°F. to 600°F. there was a trend toward decreasing interbucket-junction cracking with increasing preheat temperature.

(10) Vitallium was the only alloy employed in both submerged-melt welded and manual-arc welded tests. However, this grade was represented by material from three producers. No marked difference was found in the amount of interbucket-junction cracking in submerged-melt welded specimens as compared with manually arc-welded specimens. If anything, there was a trend toward less cracking in the manually arc-welded plates. A comparison of the materials supplied by the three producers failed to show any significant difference.

MATERIALS USED

Four principal materials were employed in conducting this investigation, (1) wrought base metal - used for both wheel disks and buckets or blades, (2) cast base metal - used for buckets or blades only, (3) submerged-melt welding rod, and (4) manual arc-welding electrodes. Since one specific aim of the project was to evaluate the weldability of typical materials, in all cases when purchasing these items the producer was furnished a specification aim or asked to select material which represented the average composition generally supplied. It was planned that complete chemical analyses would be made in the laboratory of all materials used. This work was not complete at the termination of the project.

A. Wrought Alloy Base Metal

The wrought alloys were secured from commercial producers in either finished bar form or as billets which were forged to test specimen size. Five alloys were included in the investigation. Four of these were tested in the "as forged" or "as rolled" condition, while one was solution heat treated and aged. The alloys and the respective conditions in which they were tested are listed below. The sources of the materials are given in Table 1, and the chemical analyses in Table 2.

Alloy Grade	Condition
Hastelloy "B"	As Rolled
N155 (Low Carbon)	As Forged
Timken 16-25-6	As Forged
Uniloy 19-9 DL	As Forged
S816	Heat Treated 2275°F - one hour - water quench, plus 1400°F - six hours, air cool

A regular practice was adopted of macro etch testing each individual piece of wrought base metal used in the weld test specimens. No major base metal defects were found which would be likely to influence the weldability test results.

B. Cast Alloy Base Metals

Tests were conducted on two cast alloys, Vitallium and 6059, in the "as cast" condition. It had been reported by fabricators of bucketed wheels that the weldability of the cast alloys, or at least that of Vitallium, varied with the casting producer. For this reason, castings of Vitallium were ordered from three different producers, the Austenal Laboratories, Inc., General Electric Company, and Haynes Stellite Company. The sources of the cast materials used are given in Table 1, and the available chemical analyses in Table 2.

The first design of cast test specimens used in the investigation was identified as No. NRC-1, and is shown in Figure 2. The specimen was $\frac{1}{4}$" x $1\frac{1}{2}$" x 4" overall and was cast with rough beveled edges. The pieces were used for making both the bead-on-plate and the restrained butt-joint weld tests. The regular inspection practice for these castings consisted of radiographic and macro etch examination.

The use of specimen no. NRC-1 was discontinued early in the project for two reasons. The relatively large mass of the piece made it quite difficult to cast without encountering such defects as micro-shrinkage or center unsoundness. Also, the grain size of the cast material was difficult to control, and tended to be abnormally coarse as can be seen in the photograph of the test specimen in Figure 11. Nevertheless, tests have been conducted on a number of Vitallium specimens from two different sources and 6059 specimens from one source, and the results included in this report.

The cast specimen designed for use in the wheel-and-bucket weld test was patterned after the base of an actual bucket and is shown in Figure 3. This specimen presented no particular problem to the casting producers. Specimens were ordered in four grades, Vitallium, 6059, 422-19, and X40. Time permitted the testing of only Vitallium and 6059. Inspection of these pieces included 100% radiographic examination, but no macro etch examination.

C. Submerged-Melt Welding Rod

Two grades of material, AISI Type 316 and N155 alloy, were employed as submerged-melt welding rod. It was planned to first weld all of the base metal alloys with Type 316, and after noting their relative weldability, select other welding rod compositions for trial. The one exception to this plan was the case of N155 alloy where the filler metal was to be the same grade as the base metal. A welding rod of 1/8" diameter was used throughout the work. The granular flux or melt employed was Linde Air Products Company's Unionmelt No. 80 in 20 x 200 mesh size. Pertinent data on the welding rods used are given in Table 3.

D. Manual Metallic-Arc Electrodes

Electrodes of both Type 316 and N155 alloy for making the manual-arc weld tests were prepared in the Rustless Research Laboratory by straightening and cutting a sufficient amount of 1/8" diameter submerged-melt welding rod described above and flux coating this core wire by the extrusion process.

The coatings applied on these two grades of core wire were simple lime-base type fluxes suitable for operation only on direct current-reverse polarity. Preliminary tests on these electrodes included the deposition of an all-weld-metal pad for chemical analyses, and the making of all-weld-metal tensile tests. The tensile specimens were of standard .505" diameter size secured longitudinally from a single-V restrained butt-joint in 1" thick plates of mild steel.

In Table 3 is shown the composition of the core wires, weld metals, and the weld metal tensile properties. The tensile test results with the Type 316 material are significant because they show the weld metal as such to be free from defects and to have good mechanical properties. Therefore, any weld metal defects which occur in welding heat resisting alloys are an effect of the base metal to be considered in evaluating the base metal's weldability. The tensile properties of the N155 weld metal while normal for this grade may have been affected slightly by the slag inclusions detected in the tensile specimen fracture.

WELDING TEST PROCEDURE

For the sake of brevity in the following paragraphs describing test procedure, it will be stated here that all weld tests were performed using two welding processes, submerged-melt welding and manual arc-welding. The same jigs or fixtures were used for clamping or restraining the joint assembly when using either process. Preheating was done by means of a gas burner and the temperature measured with a thermocouple and Potentiometer.

The submerged-melt welding equipment consisted of a Type "U" Unionmelt head and carriage. All of the submerged-melt welding was done with alternating current. The welding current was supplied by two 500 ampere size General Electric Company transformers. Towards the end of the investigation, while the wheel-and-bucket specimens were being welded, the machine was equipped with an Esterline-Angus recording ammeter and voltmeter.

The manual arc-welding equipment consisted of a 400 ampere size Westinghouse motor-generator welding machine. All of the arc-welding was performed using direct current-reversed polarity.

A. Bead-on-Plate Test

The base metal pieces for this test measured ¾" thick x 1½" wide x 4" long. Wrought materials were secured in ¾" x 1½" flat bars which were cut into 4" sections. Cast alloys were used in the NRC-1 design specimens as shown in Figure 2. In making the test, a weld bead about 3" long was deposited longitudinally on one face.

It was intended that the only variable in this test should be the base metal composition. Therefore, welding conditions were selected for the submerged-melt and manual-arc processes and held constant. The conditions used were as follows:

	Submerged-Melt Process		
	Condition A	Condition B	Manual-Arc Process
Current - Amperes	300	600	110
Closed Circuit Volts	28	28	25
Travel Speed - "/min.	10	25	8
Heat Input - Joules/in.	50,400	40,320	20,625

Two conditions were used for welding by the submerged-melt process to study the influence of varying amounts of base metal diluting the weld metal. The amount of dilution with Condition A was generally in the order of 50%. Condition B gave much deeper penetration into the base metal and the amount of dilution averaged about 70%. Two specimens were made by each condition in each process, one with the base metal at room temperature (75°F.) and the other preheated to 600°F.

Examination of the welded test piece consisted of removing sections as shown in Figure 4 and preparing them for macro etch and metallographic inspection. A series of macro etch specimens from typical bead-on-plate tests is shown in Figure 10.

B. Restrained Butt-Joint Test

The restrained butt-joint test specimen, designed to represent the bucket-to-disk joint found in welded bucketed wheels, is shown in Figure 5. The features of the specimen, which correspond to salient features of a bucketed wheel and which were intended to promote the welding defects, were (1) the relatively large mass of the base metal pieces, (2) the restraint upon these pieces, and (3) the notch in the bottom of the joint.

It will be noted in Figure 5 that the assembly for making the test specimen consists of two pieces of base metal $\frac{3}{4}$" thick x 3" wide x 4" long placed in juxtaposition with edge preparation to make an included 70° single-V joint with an abutting root face. For reasons concerning casting practice, it appeared necessary to limit the size of cast base metal pieces to about $\frac{3}{4}$" thick x $1\frac{1}{2}$" wide x 4" long, or one-half the required width. Therefore, two cast pieces were joined together with a double-V butt-joint to make each side of the test specimen. The same practice was used in handling the wrought alloys to maintain the same test conditions.

The first restrained butt-joint specimens completed were made of only a single base metal alloy. In welding specimens, an attempt was made to maintain the same weld bead size and shape in each. This required frequent changes in the submerged-melt welding conditions because of the wide differences in the properties and characteristics of the alloys. The welding operation was done with the base metal initially at room temperature and a maximum interpass temperature of 150°F. While it was planned to conduct further tests using (1) a 600°F. preheat temperature, (2) combinations of a wheel alloy and a bucket alloy, and (3) segments of a bucket alloy in lieu of a solid piece, this type specimen was discontinued because of extreme difficulty in producing sound cast base metal pieces having near-normal grain size.

Despite the discontinuance of the restrained butt-joint type specimen, the examination of those test plates already welded was carried to completion. The specimens were sectioned as shown in Figure 5. In addition to macro etch and metallographic examination for defects, bend tests and tensile tests were prepared to secure rough data on the mechanical properties of the joint. In Figure 11 is shown typical macro etch specimens from restrained butt-joint tests welded by both processes.

C. Wheel-and-Bucket Design Test

The wheel-and-bucket specimen represented a more direct approach to the objective of reproducing the defects found in the weld joints of bucketed wheels. This design was avoided at the start of the project because of the time required to prepare the base metal pieces. The test specimen design, method of assembly, and procedure in filling the joint by submerged-melt welding or manual arc-welding is shown in Figure 6. Either type of specimen was clamped in the heavy restraining jig shown in Figure 7. This fixture and all accessories were made of non-magnetic metals to minimize magnetic phenomena during welding. The bolts and nuts appear dark in the photograph because they were subjected to a newly developed surface blackening treatment to reduce seizing and galling when used at the preheat temperatures. The measured-torque wrench also shown in this figure was used for tightening the horizontal screws which applied pressure to the abutting root faces of the joint and the interbucket faces, and the vertical clamping bolts. Torque forces of 35 foot-pounds and 140 foot-pounds respectively were applied.

The arrangement of equipment for welding by either the submerged-melt or manual-arc process is shown in Figure 8. The jig containing the specimen was supported by two stub shafts and bearings. Preheating was done by means of a large circular three-section gas burner. A light sheet-metal covering was placed over the top of the jig during the heating operation to improve temperature uniformity. The temperature was measured at all times by means of thermocouples imbedded in both faces of the wheel piece approximately 5/8" from the beveled edge. The two thermocouples were connected by a two-way knife switch to a recording potentiometer. The thermocouple on top which was away from the direct effect of the heating flames was always used. Figure 9 is a more detailed photograph of the equipment arrangement for submerged-melt welding.

In depositing the weld metal, either by submerged-melt or manual-arc welding, the jig and specimen (and submerged-melt flux) were slowly brought up to the specified preheat temperature and held at temperature approximately five minutes. After depositing the first pass of weld metal, the assembly was allowed to dissipate the heat input. Upon returning to the initial preheat temperature, the second pass was deposited. Thus in the wheel-and-bucket weld test, the interpass temperature was the same as the preheat temperature. The only exception was in the case of no preheat (base metal initially at room temperature) where an interpass temperature of 150°F was used.

Welding the wheel-and-bucket design test specimens by the submerged-melt process required considerable care because of the short length of the test joint. The 8" long specimen permitted only a travel distance of 2" in which to adjust the controls of the machine to secure the proper deposit shape. A narrow weld deposit having vertical sides which terminated in a rounded root was desired in the wheel-and-bucket specimen since this shape was preferred by fabricators of welded wheels. The fabricators believed that a deposit having a wide top and tapering sides to the root point was hyper-sensitive to radial notch extension because of the relatively thin section adjacent to the interbucket junction at the surface.

In a given set of conditions for submerged-melt welding, the factor which has the greatest influence on the deposit shape is the distance between the rod and work during deposition, or from another viewpoint, the closed circuit voltage. When welding the wheel-and-bucket specimens, if a closed circuit voltage of approximately 29 or greater was used, a "wide" bead such as shown in Figure 13 would be deposited. If the closed circuit voltage was approximately 25 to 29, a "narrow" bead like that shown in Figure 14 would be secured.

Welding the wheel-and-bucket design specimen by the manual-arc process presented no particular difficulty. Figure 15 illustrates a typical welded test plate and the shape of the weld joint as revealed by a macro etch specimen.

The procedure for the examination of the welded wheel-and-bucket specimens is illustrated in Figure 6 and outlined below.

(1) Macro etch specimens were prepared from discard portions at each end of the test plate. These specimens were examined for weld metal defects, and were also used to determine the percentages of wheel metal, base metal and filler in the weld deposit. The test plate, after removal of the discard, was 4" long and contained eight buckets.

(2) Measurement of interbucket notch extension was made by grinding the top and bottom welds flush with the wheel and bucket surfaces and examining the seven interbucket junctions on either side with a 25-power microscope. The weld surface was finished with a no. 1 grit metallographic paper, and any extension of the junction into the weld metal was measured with a scale graduated in 64ths of an inch. However, to make these data more easily compared, the measurements were expressed in thousandths of an inch.

(3) Radiographic examination was next made of the 4" long test plate. The exposure was made normal to the plate surface. A penetrameter made of N155 alloy representing 2% of the test specimen thickness was placed on the weld joint.

TEST RESULTS

A. Bead-on-Plate and Restrained Butt-Joint Tests

Seven heat resisting alloys as listed below were tested for weldability by means of the bead-on-plate and restrained butt-joint weld tests.

Hastelloy "B"	S816
N155	Vitallium
Timken 16-25-6	6059
Uniloy 19-9 DL	

Using a single base metal alloy in either type of weld test, eight specimens as described below were prepared with each alloy:

Submerged-Melt Welding

(1) Bead-on-plate, current 300 amperes, room temperature
(2) Bead-on-plate, current 300 amperes, 600°F. preheat
(3) Bead-on-plate, current 600 amperes, room temperature
(4) Bead-on-plate, current 600 amperes, 600°F. preheat
(5) Restrained butt joint, room temperature

Manual Arc-Welding

(6) Bead-on-plate, room temperature
(7) Bead-on-plate, 600°F. preheat
(8) Restrained butt-joint, room temperature

Type 316 weld filler metal was used in all cases except that of alloy N155 where filler metal of the same composition was used.

The results of the bead-on-plate test for each alloy using the submerged-melt process are shown in Table 4. The results of this test using the manual-arc process are shown in Table 5. The results of the restrained butt-joint tests welded by both processes are contained in Table 6. It can be seen from the data in these tables that the only kind of defect which appeared in the weldability tests was intergranular cracking or fissuring. Such defects as porosity or abnormally large non-metallic inclusions never presented a problem.

The cracks were found in both the heat-affected-zone of the base metal and in the weld metal. In a few cases cracks in the heat-affected-zone were found to have propagated into the weld metal. No instances of cracks following the fusion line or zone were found.

In Figure 12 is shown the appearance of intergranular cracking in the heat-affected-zone of a manually arc-welded joint in S816 alloy. This condition was found at the junction of two weld beads in restrained butt-joint specimen No. M-21. It is suspected that the cracking is due either to the melting of intergranular compounds or to low ductility resulting from the presence of these compounds at the grain boundaries.

The following tabulation summarizes the types of cracking found in the various specimens of each grade.

Base Metal	Submerged-Melt Bead-on Plate (300A)	Submerged-Melt Bead-on Plate (600A)	Submerged-Melt Restrained Butt-Joint	Manual-Arc Bead-on Plate	Manual-Arc Restrained Butt-Joint
Hastelloy	None	None	None	None	((WM))
N155	HAZ, WM	None	(Not Made)	None	WM
Timken	None	None	None	None	(WM)
Uniloy	WM	None	WM	None	WM
S816	None	None	None	None	HAZ, WM
Vitallium	HAZ, WM	HAZ, WM	HAZ, WM	HAZ, WM	WM
6059	WM	WM	(Not Made)	HAZ	HAZ, WM

WM - Cracking in Weld Metal
HAZ - Cracking in Heat-Affected-Zone
( ) - Parentheses denote only slight cracking

The mechanical properties secured from tensile and bend tests on the restrained butt-joints are given in Table 7.

Some brief notes on the microstructure of the base metal and weld metal are presented below.

Base Metal Alloy	Base Metal Microstructure	Weld Metal Microstructure Submerged-Melt	Weld Metal Microstructure Manual-Arc
Hastelloy "B"	Austenitic-like grains. Small clusters of carbides.	Austenite, small amount of delta ferrite, carbides.	Austenite, small amount of delta ferrite, carbides.
N155	Austenite, inter and intra granular carbides.	Austenite and carbides.	Austenite and carbides.
Timken 16-25-6	Austenite, inter and intra granular carbides.	Austenite, small amount of delta ferrite, carbides.	Austenite, small amount of delta ferrite, carbides.
Uniloy 19-9 DL	Austenite, inter and intra granular carbides.	Austenite, some delta ferrite, carbides.	Austenite, some delta ferrite, carbides.
S816	Austenite-like grains, complete intergranular carbide network, intragranular carbides.	Austenite and carbides.	Austenite and carbides.
Vitallium	Austenite-like grains, complex carbides.	Austenite and complex carbides.	Austenite and complex carbides.
6059	Austenite-like grains, complex carbides.	Austenite and complex carbides.	Austenite and complex carbides.

B. Wheel-and-Bucket Design Test

A testing program consisting of six sections using the wheel-and-bucket design specimen was planned for the investigation. The program is completely outlined in Table 8. In brief, the main objectives of the work were the determination of the following.

(1) Influence of preheat temperatures
(2) Weldability of eight bucket alloys
(3) Weldability of two alloys for cold type wheels
(4) Weldability of three alloy combinations for hot type wheels
(5) Weldability of two alloys for weld filler metals
(6) Weldability of two alloys for both the buckets and wheels for gas turbines

In these tests, three materials were used as arbitrary standards, Timken 16-25-6 alloy for the wheel, S816 alloy for the buckets, and Type 316 for the filler metal.

At the time this project was terminated, about one-third of the approximately eighty planned wheel-and-bucket design test specimens had been welded. Only five of these specimens were manual arc-welded. Of the six series of tests mentioned above, the completed specimens represented (1) the influence of preheat temperature, (2) the weldability of bucket alloys, and (6) the weldability of alloys for gas turbines. Examination of the specimens had progressed to the extent of having macro etch specimens prepared, notch extension measured and radiographic examination made.

As a whole, the macro etch specimens revealed only a few defects. In the test plates having wrought alloy buckets and welded by the submerged-melt process, only those of S816 alloy were found to have defects. Three out of six plates contained small weld metal cracks as shown below:

Specimen No.	Wheel Alloy	Bucket Alloy	Filler Metal	Remarks
U-39	Uniloy 19-9 DL	S816	Type 316	One small weld metal crack
U-54	Timken 16-25-6	S816	Type 316	Two small weld metal cracks
U-58	Timken 16-25-6	S816	Type 316	One small weld metal crack

In the test plates having cast alloy buckets welded by either process, cases were found of weld metal cracking and the peculiar cracking in the heat-affected-zone of the cast alloy which propagates into the weld metal. The specimens which contained defects were:

Specimen No.	Wheel Alloy	Bucket Alloy	Filler Metal	Remarks
U-43	Timken 16-25-6	Vitallium	Type 316	Small crack from HAZ into WM
U-45	Timken 16-25-6	Vitallium	Type 316	Small crack in WM
U-51	Timken 16-25-6	Vitallium	Type 316	Two cracks in WM
U-59	Timken 16-25-6	Vitallium	Type 316	Small crack in WM
U-50	Timken 16-25-6	6059	Type 316	Small crack from HAZ into WM
M-30	Timken 16-25-6	Vitallium	Type 316	Small crack from HAZ into WM

After grinding the weld beads flush with the wheel and bucket surfaces, it was found that the test specimen had successfully induced notch extension into the weld metal. The appearance of the cracks or extensions which propagated from the interbucket junctions compared favorably with those found in turbo-supercharger wheels. This can be seen by comparing Figure 17, which shows the bottom weld bead of specimens no. U-36 after grinding and finishing with metallographic paper, with Figure 1.

The technique of measuring the length of these extensions on a surface thus prepared was admittedly lacking in accuracy. Nevertheless, in view of the metallographic examination which was to be made, it appeared best to refrain from etching the specimens to more clearly reveal the defects. Notch extension data for wheel-and-bucket specimens welded by the submerged-melt process are shown in Table 9, and by the manual-arc process in Table 10. When measuring these defects in a specimen, a record was made of the length at the top and bottom of each junction. However, since the lengths were reasonably consistent, the practice of totaling the lengths of extensions in a single weld bead was used for convenience in reporting. In Tables 9 and 10 these totals for top and bottom beads have been added together and then divided by fourteen to secure the average notch extension per junction.

In examining the results of submerged-melt welded tests in Table 9, there appears at first glance, to be very poor agreement between a number of duplicate specimens as to notch extension susceptibility. It will be noted, however, that the shape of the weld deposit has been listed in the table, and that this provides an explanation for the disagreement. The suspicion of wheel manufacturers that "wide" beads (this term also implies sharply tapered sides) are more susceptible to interbucket notch extension is confirmed by these data. A few specific examples which may be pointed out in this table are described below:

(1) Compare test specimen nos. U-38 and U-58, both of which consist of Timken 16-25-6 alloy wheel - S816 alloy buckets - Type 316 filler metal. Specimen no. U-38 was welded with a wide deposit and possessed an average notch extension per junction of .173". Specimen U-58 was welded with a narrow deposit and averaged only .029" notch extension per junction.

(2) Specimen no. U-45 was made of a Timken 16-25-6 wheel, Vitallium buckets, and Type 316 filler metal. In this case the top weld bead was wide and had an average of .069" extension per junction, while the bottom weld bead was narrow and had only .022" per junction.

(3) Further confirmation is found in specimen no. U49 which was also made of Timken alloy, Vitallium, and Type 316 materials. In this specimen both the top and bottom weld deposits varied from the wide type at the start to the narrow type at the finish. In Figure 16 is shown the appearance of the top and bottom of the as-welded plate and the macro etch specimens from each

end. The length of extension measured at each inter-bucket junction appears in the photographs. The more severe extensions have occurred in the wide portion of the deposits on either side.

Attention should be called to the fact that all of the alloys tested did not show an increased susceptibility to notch extension with wide deposits. Bucket alloys S816, Vitallium, and 6059 all appeared to promote this increased cracking in the wider beads. Alloy S816 was the most prominent example. On the other hand, Timken 16-25-6, Hastelloy "B" and N155 when used as bucket alloys produced not only a lower average of notch extension than the alloys mentioned above, but gave similar results with both wide and narrow deposits.

The radiographs indicated no defects in any of the specimens except the interbucket notch extensions into the weld metal. The cracks in the weld metal and heat-affected-zone previously noted in the macro etch specimens were apparently of such size and shape as to be undetectable by X-ray examination. The radiographs were of little value in determining more accurately the length of notch extension. The extensions in the top and bottom weld bead were, of course, superimposed on each other. In several test plates, lengthy extensions were seen on the weld metal surface which were revealed to a lesser degree in the radiograph.

It was planned that some sections of the test specimens for metallographic examination would be removed by nicking and fracturing through the notch extensions. In this way the characteristics of the crack surfaces could be studied. Sufficient time was available to nick-fracture only a small number of specimens. No metallographic work was conducted.

An indication of the difficulty involved in accurately determining the degree of notch extension is shown in Figure 18. This figure illustrates the fact that the maximum extension may occur at the center of the weld joint rather than the top or bottom surface. A procedure suggested for future work to overcome this problem consists of cutting one-half of the test plate into a three-layer "sandwich" to permit measurements at four additional levels through the ¾" thick section.

APPENDIX I

APPENDIX I (Cont'd).

Figure 1 Aircraft Turbo-Supercharger Wheel Welded by the Submerged-Melt Process having Interbucket Notch Extensions into Weld Metal.

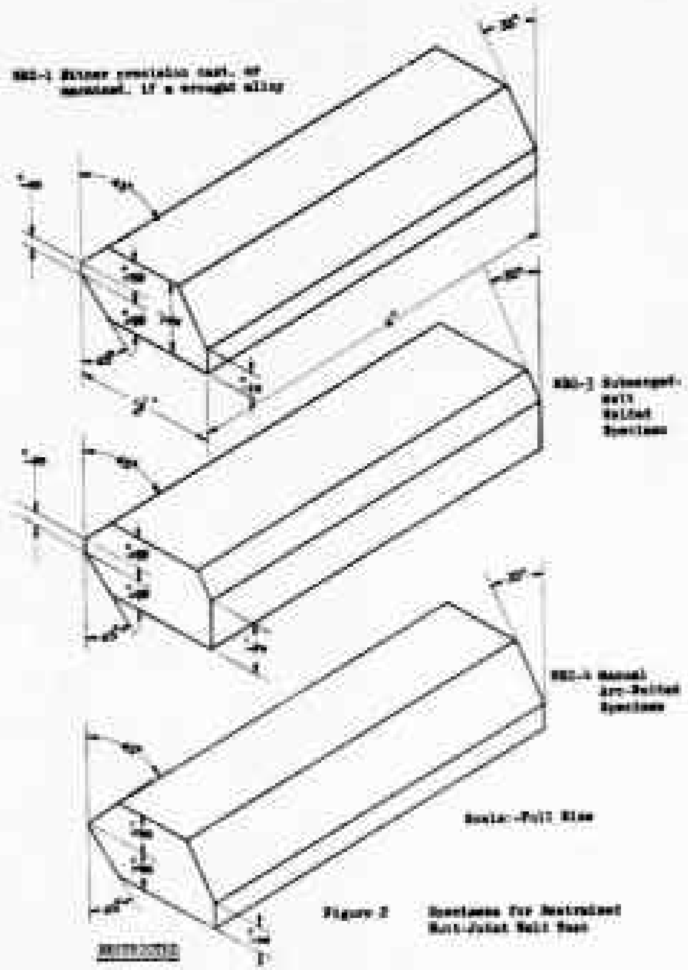


Figure 2 Specimens for Restrained Butt-Joint Weld Test

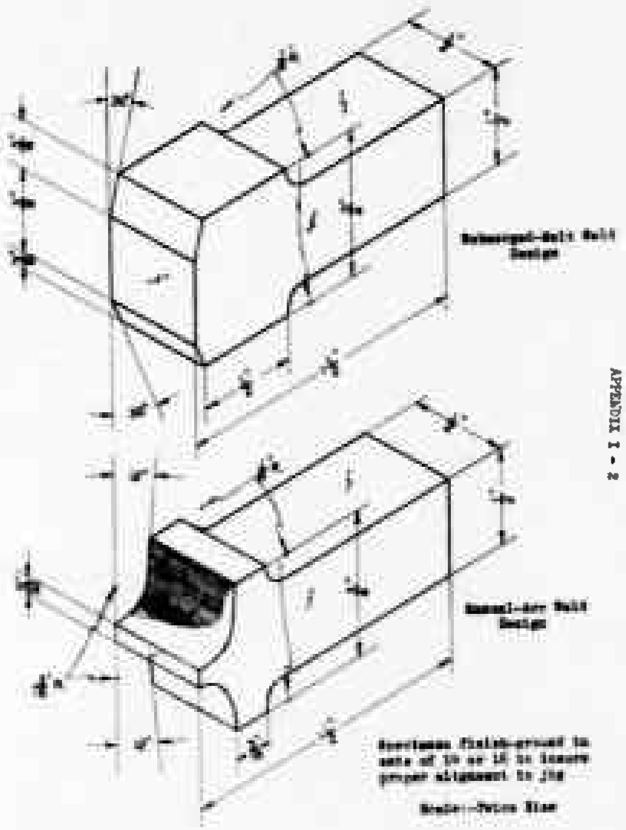
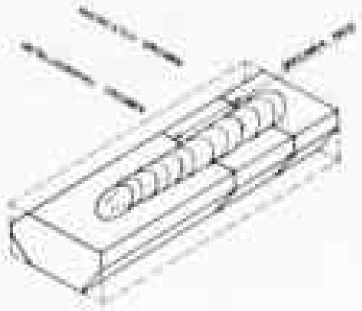


Figure 1 Bucket-Base Replica for Wheel-and-Bucket Design Weld Test

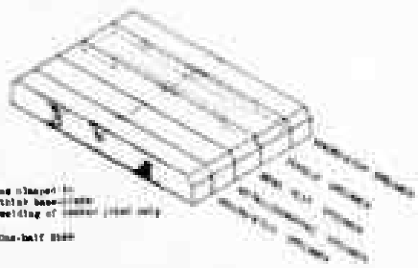


Solid figure is WRC-1 precision cast materials design

Dotted lines indicate design used for wrought base metals

Scale:-Full Size

Figure 4 Bead-on-Plate Weld Test



Specimens clamped to 1 1/2" thick base-plate during welding of [illegible] joint only

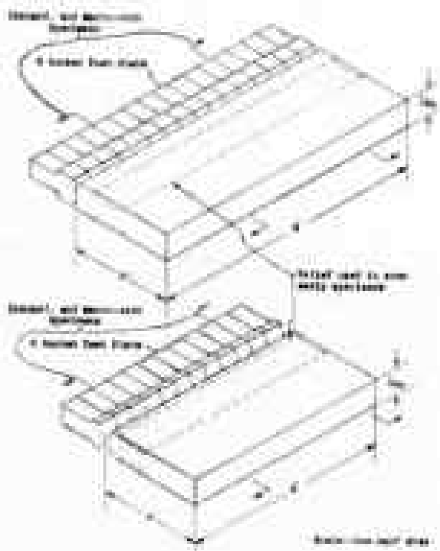
Scale:-One-half Size

Joint Design for Submerged-Melt Welding Process

Joint Design for Manual Arc-Welding Process

Scale:-Full Size

Figure 5 Restrained Butt-Joint Weld Test



Scale:-One-half Size

Figure 6 Wheel-and-Bucket Design Weld Test

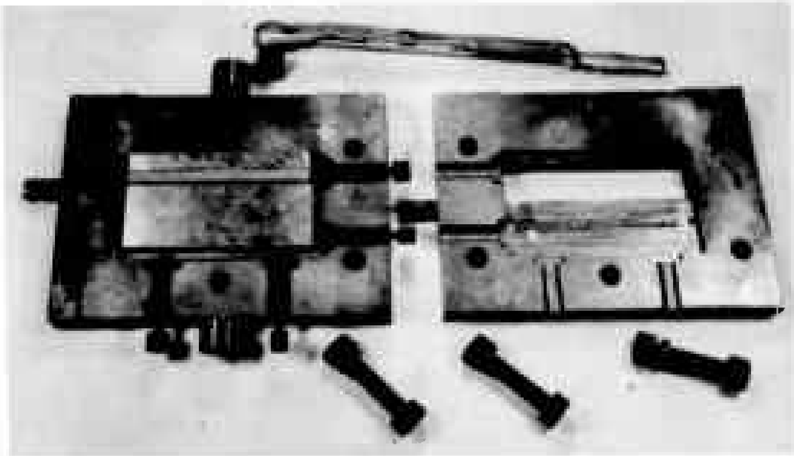


Figure 7 Welding Fixture for Holding Wheel-and-Bucket Design Test Specimen. A Specimen for Submerged-Melt Welding is in Place. The Measured-Torque Wrench is Used for Tightening All Bolts.

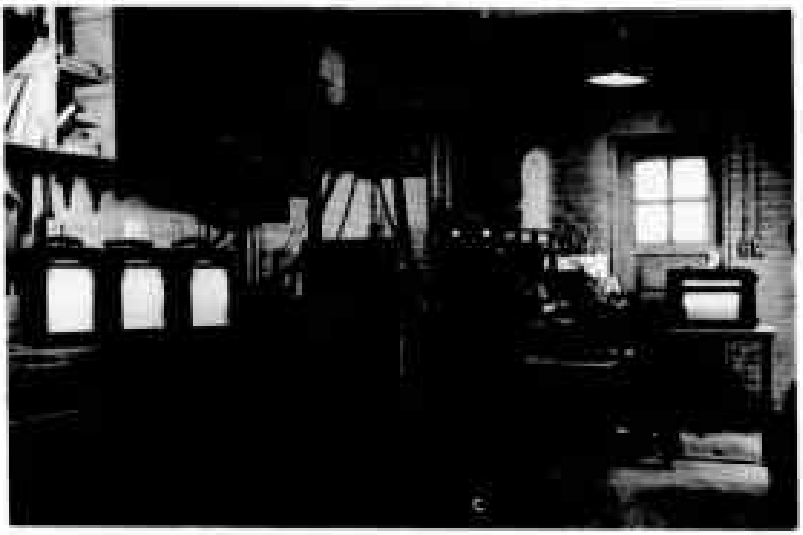


Figure 8 Equipment for Submerged-Melt and Manual-Arc Welding. (A) Welding Fixture Poised Over Gas Burner. (B) Recording Potentiometer for Temperature Measurement. (C) Metal Cover for Fixture During Heating Cycle. (D) Recording Instruments for Welding Current.

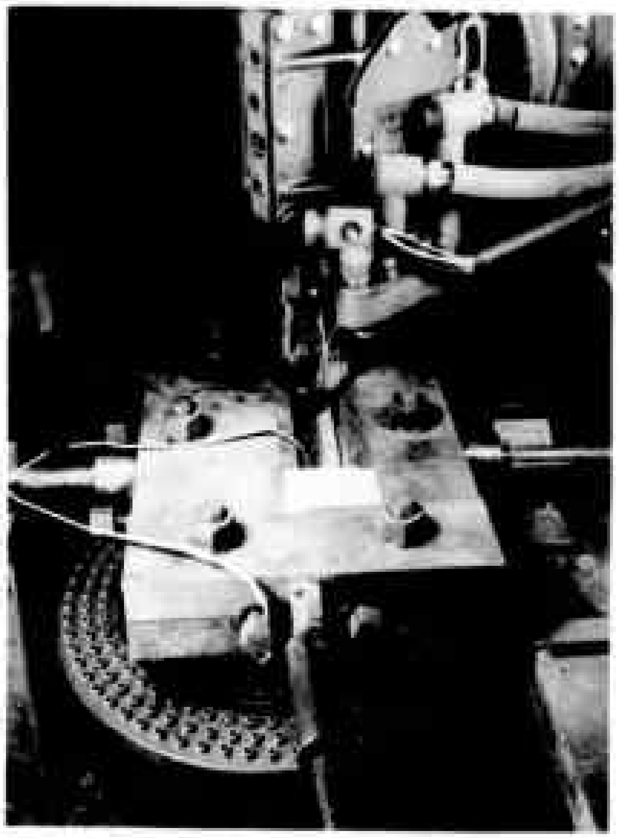
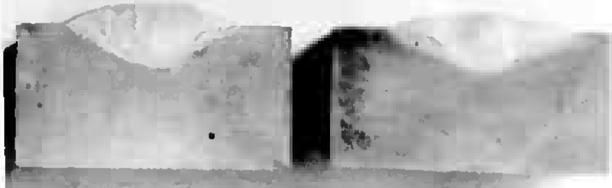


Figure 9 Position of Equipment for Welding Wheel-and-Bucket Design Specimen by the Submerged-Melt Process

APPENDIX I - 6

UC1 - UNILOY 19-9 DL

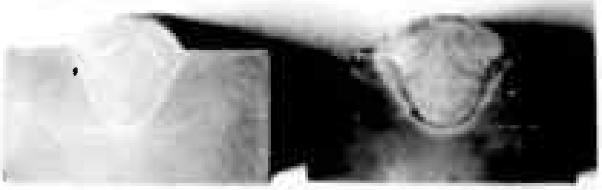
BEAD ON PLATE MACRO ETCH SPECIMEN
SUBMERGED ARC PROCESS - 300 Amp.



Room Temperature 600°F. Preheat

UC1 - UNILOY 19-9 DL

BEAD ON PLATE MACRO ETCH SPECIMEN
SUBMERGED ARC PROCESS - 600 Amp.



Room Temperature 600°F. Preheat

UC1 - UNILOY 19-9 DL

BEAD ON PLATE MACRO ETCH SPECIMEN
MANUAL METALLIC D. C. ARC PROCESS

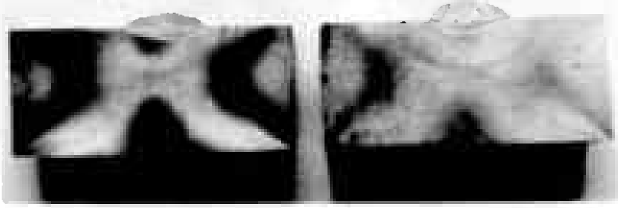


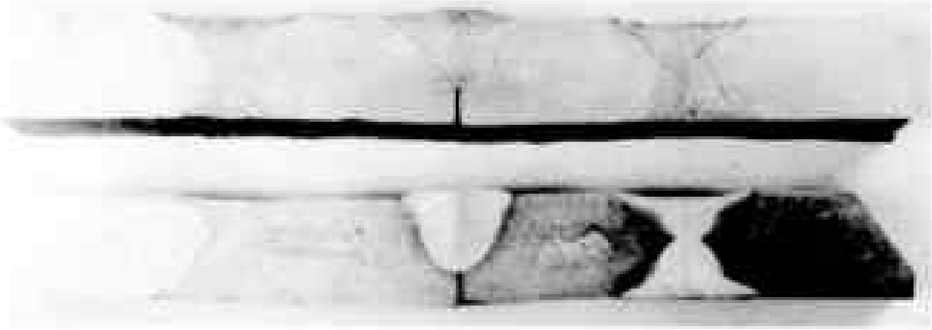
Figure 10 Typical Macro Etch Specimens from Bead-on-Plate Weld Tests Showing Size and Shape of Weld Deposits.

APPENDIX I - 7

HS1 - HASTELLOY "B"

RESTRAINED JOINT MACRO ETCH SPECIMEN
SUBMERGED ARC PROCESS - 300 Amp.

ROOM TEMPERATURE



AL1 - VITALLIUM

RESTRAINED JOINT MACRO ETCH SPECIMEN
MANUAL METALLIC D.C. ARC PROCESS

ROOM TEMPERATURE

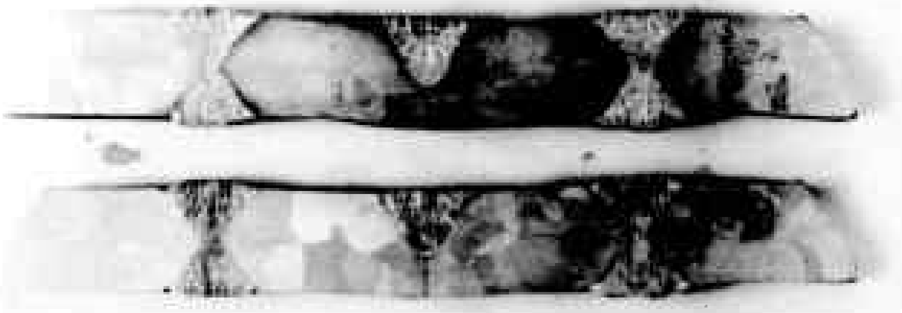


Figure 11 Typical Macro Etch Specimens from Restrained Butt-Joint Weld Tests Showing Size and Shape of Weld Deposits.

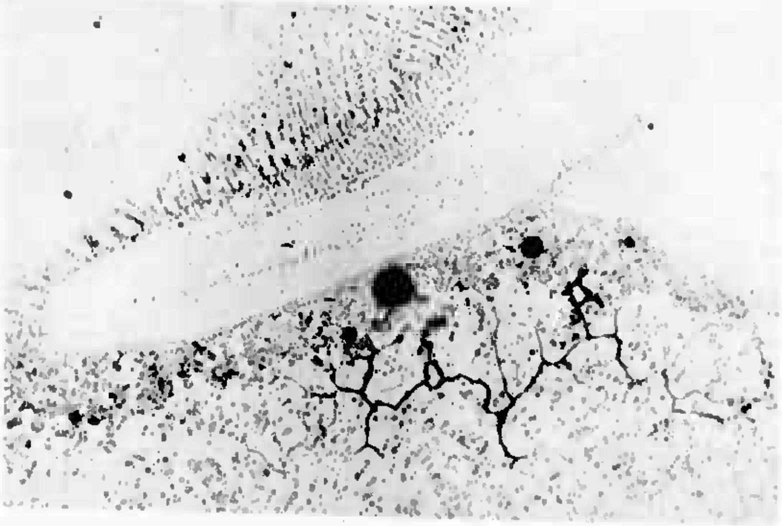


Figure 12 Intergranular Cracking in Heat-Affected-Zone of S816 Alloy Base Metal. Restrained Butt-Joint Test Specimen No. M-21, Manual-Arc Welded. Located at Junction of Two Weld Beads.

Etchant - 10% Chromic Acid (Electrolytic)
Magnification 250 X

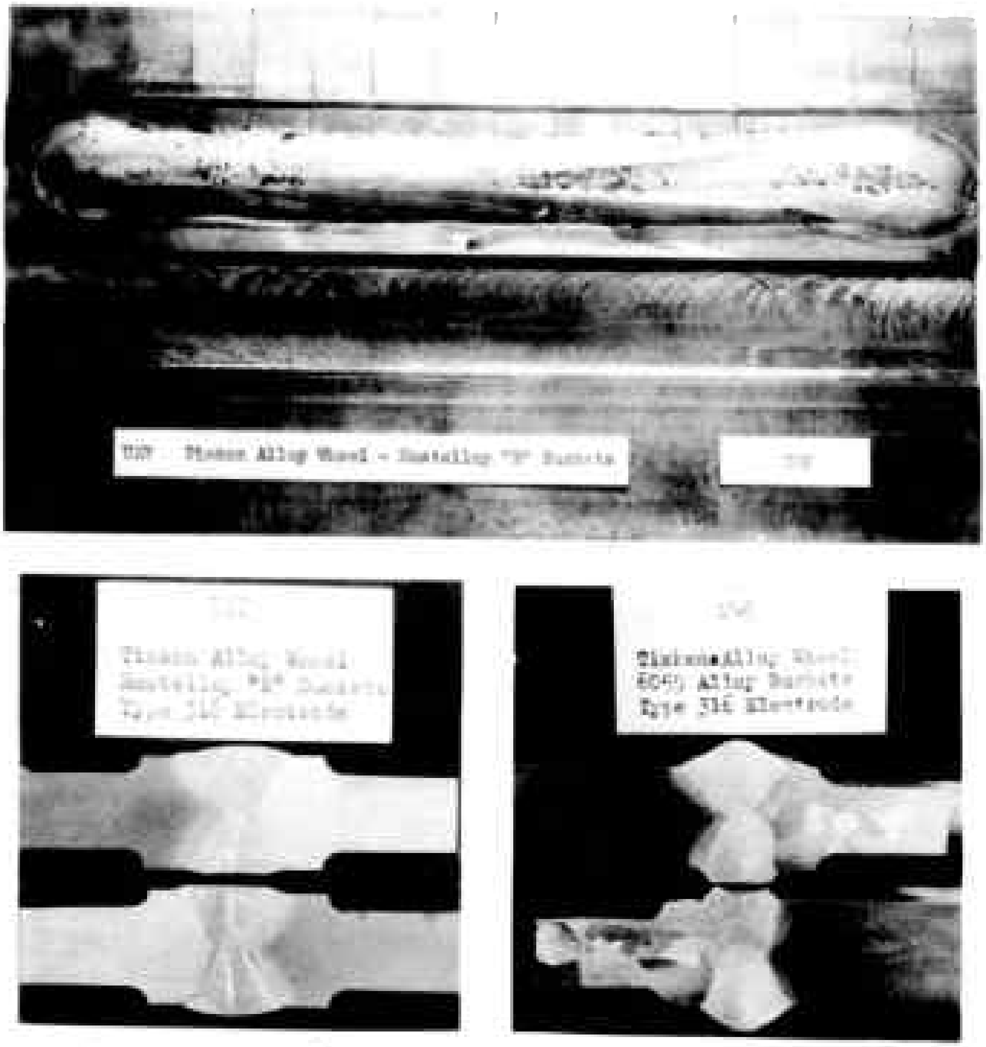


Figure 13 Typical Wheel-and-Bucket Design Test Specimens Welded by the Submerged-Melt Process. Weld Beads are "Wide" Type Deposite. As Welded Plate above, Macro Etch Specimens below.

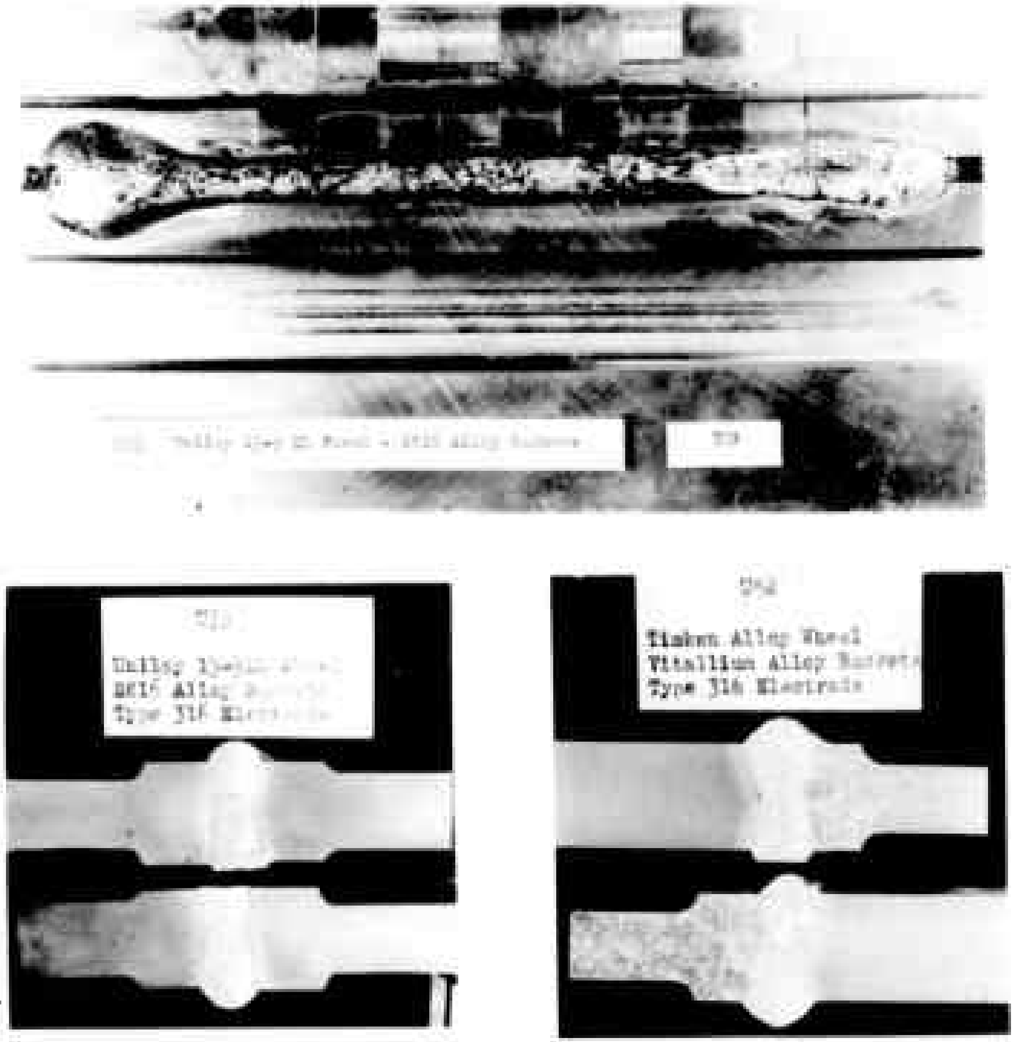


Figure 14 Typical Wheel-and-Bucket Design Test Specimens Welded by the Submerged-Melt Process. Weld Beads are "Narrow" Type Deposits. As Welded Plate above, Macro Etch Specimens below.

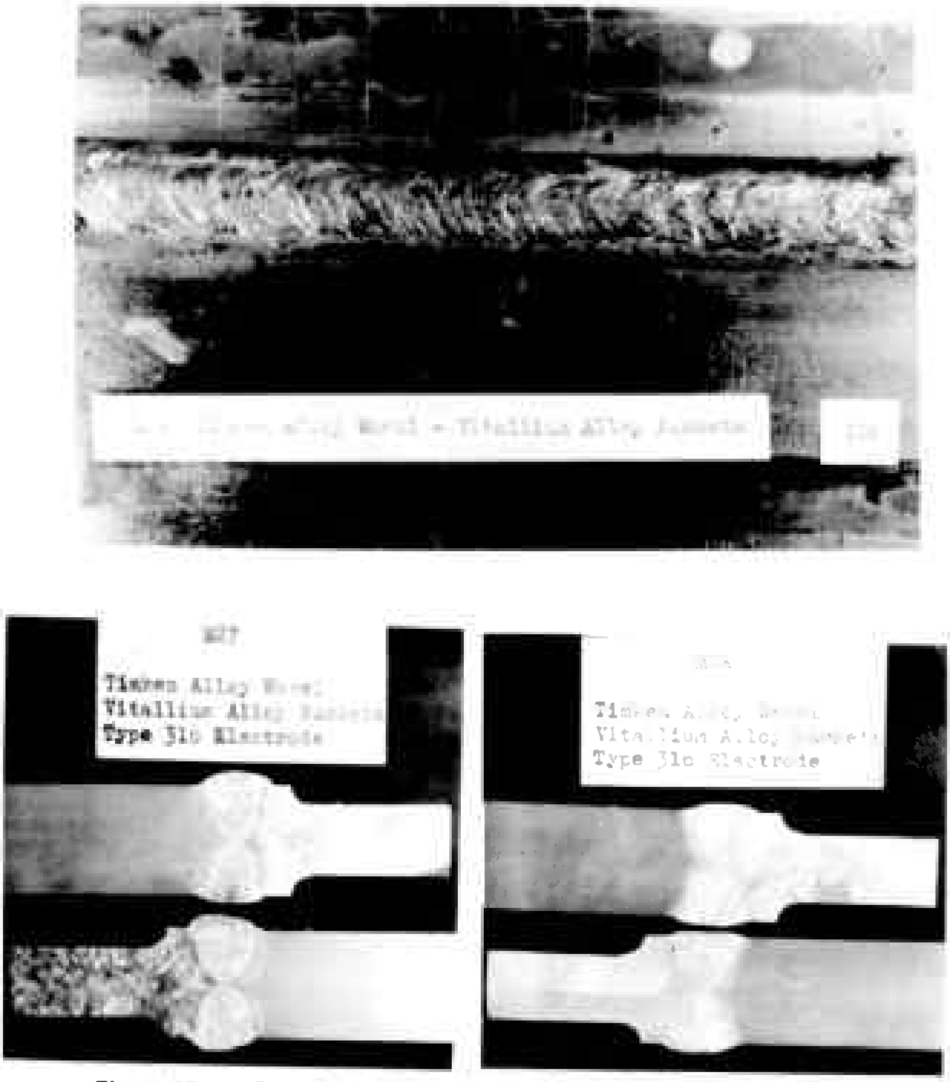


Figure 15 Typical Wheel-and-Bucket Design Test Specimens Welded by the Manual-Arc Process. As Welded Plate above, Macro Etch Specimens below.

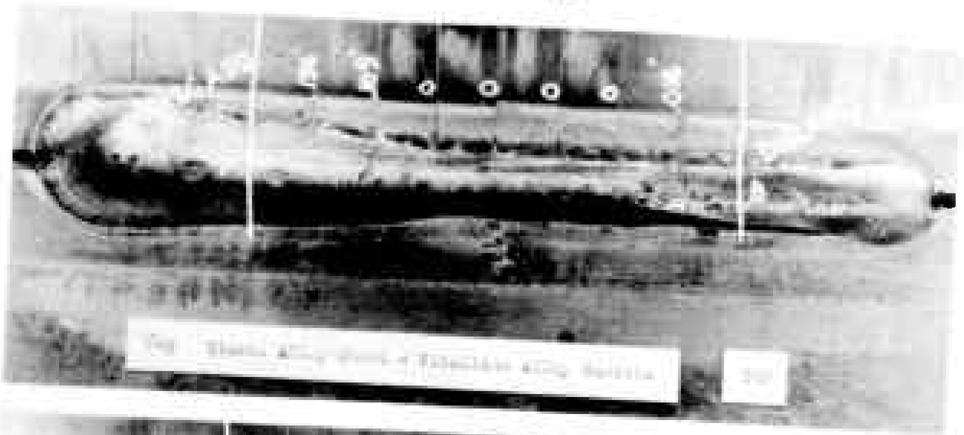


Figure 16 Wheel-and-Bucket Design Specimen No. U-49 Welded by the Submerged-Melt Process. Note that Weld Beads Change from "Wide" Type Deposit at Start, to "Narrow" Type Deposit at Finish. Notch Extensions are more Severe in "Wide" Portion of Weld Beads. Further Details on this Test are Presented in Section on Test Results.

Figure 17 Wheel-and-Bucket Design No. U-36 Welded by Submerged-Melt Process Showing Appearance of Severe Notch Extension in Bottom Weld Bead.

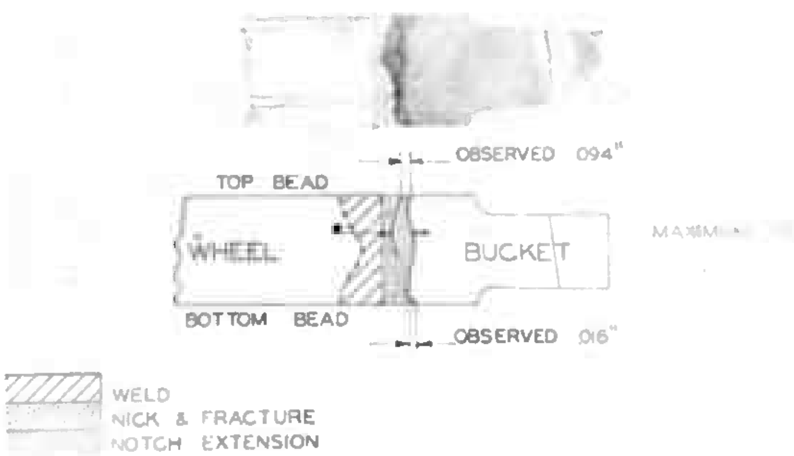


Figure 18 First Bucket Removed from Wheel-and-Bucket Design Test Specimen No. U-43 by Nick and Fracture Technique. Note that Maximum Notch Extension Has Occurred Near Center of Section Rather than at the Surface.

APPENDIX II

APPENDIX II - Table 1

Sources of Base Metal Alloys

Trade Name	Material	Condition	Source of Supply	Heat Number	Laboratory Identification*
Group A - Wrought Base Metal Alloys					
Hastelloy "B"	3/4 x 1 1/2" Bars	As Forged	Haynes Stellite Company	-	HS1
Hastelloy "B"	3/4 x 1 1/2" Bars	As Forged	Haynes Stellite Company	-	HS7
N155	3/4 x 1 1/2" Bars	As Forged	Bethlehem Steel Company	BX4263	BS1
N155	3/4 x 1 1/2" Bars	As Forged	Bethlehem Steel Company	GX7003	BS2
N155	3/4 x 3" Bars	As Forged	Bethlehem Steel Company	GX8106	BS3
Timken 16-25-6	4" sq. Billet	As Forged	Timken Roller Bearing Company	12226	TR1
Timken 16-25-6	4" sq. Billet	As Forged	Timken Roller Bearing Company	13182	TR2
Uniloy 19-9 DL	4" sq. Billet	As Forged	Universal-Cyclops Steel Corporation	B10810	UC1
S816	3/4 x 1 1/2" Bars	Annealed	Allegheny-Ludlum Steel Corporation	-	AS1
Group B - Cast Base Metal Alloys					
Vitallium	3/4 x 1 1/2 x 4"	NRC-1 As Cast	Austenal Laboratories, Inc.	W7588	AL1
Vitallium	Bucket Bases	NRC-5 and 6 As Cast	Austenal Laboratories, Inc.	W8176 and W8307	AL3
Vitallium	3/4 x 1 1/2 x 4"	NRC-1 As Cast	General Electric Company	-	GE1
Vitallium	Bucket Bases	NRC-5 and 6 As Cast	General Electric Company	7264	GE3
Vitallium	Bucket Bases	NRC-5 and 6 As Cast	Haynes Stellite Company	-	HS5
6059	3/4 x 1 1/2 x 4"	NRC-1 As Cast	Austenal Laboratories, Inc.	W6216	AL2
6059	Bucket Bases	NRC-5 and 6 As Cast	Austenal Laboratories, Inc.	W6216 and W6423	AL4

* First two letters of identification indicate source, digit is consecutive number of item ordered from source.

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APPENDIX II - Table 2

Chemical Composition of Base Metal Alloys

Trade Name	Material	Lab No.	Analyst (1)	C	Mn	P	S	Si	Cr	Ni	Co	Mo	W	Cb	Ti	V	N
Group A - Wrought Base Metal Alloys																	
Hastelloy "B"	$\frac{3}{4}$x1$\frac{1}{2}$" Bars	HS1	Laboratory	.030	.40			.24		66.07		28.00	(Fe 4.70)			.23	
Hastelloy "B"	$\frac{3}{4}$x1$\frac{1}{2}$" Bars	HS7	Laboratory	.044	Nil	.011	.002	.18		65.17		26.60	(Fe 8.55)			.17	
N155	$\frac{3}{4}$x1$\frac{1}{2}$" Bars	BS1	Laboratory	.118	1.47	.012	.003	.63	22.22	19.90	20.50	2.66	1.76	.92			.141
N155	$\frac{3}{4}$x1$\frac{1}{2}$" Bars	BS2	Supplier	.13	1.50	.020	.015	.43	21.76	20.80	21.80	3.28	2.13	.94			.12
		BS2	Laboratory				.019		21.81		22.27			.94			
N155	$\frac{3}{4}$x 3" Bars	BS3	Supplier	.11	1.48	.018	.024	.70	22.07	20.32	21.48	2.66	2.60	1.10			.14
		BS3	Laboratory				.022		22.21		21.00			.90			
Timken 16-25-6	$\frac{3}{4}$x1$\frac{1}{2}$" Bars	TR1	Supplier	.09	1.72	.016	.019	.62	16.15	25.51		6.43					.144
		TR1	Laboratory	.086	1.72	.018	.017	.59	16.13	25.77		6.35					.143
Timken 16-25-6	$\frac{3}{4}$x 3" Bars	TR2	Supplier	.082	1.72	.017	.017	.85	16.66	27.75		6.22					.15
		TR2	Laboratory	.080	1.72	.022	.014	.90	16.94	25.96		6.24					.076
Uniloy 19-9 DL	$\frac{3}{4}$x1$\frac{1}{2}$" Bars	UC1	Supplier	.30	1.09	.016	.014	.38	18.97	9.18		1.24	1.50	.52	.32		
		UC1	Laboratory	.306	1.08	.021	.004	.63	18.98	9.04		.99	1.75	.40	.32		
SS16	$\frac{3}{4}$x1$\frac{1}{2}$" Bars	AS1	Laboratory	.373	.46	.005	.004	.43	20.15	20.57	44.24	3.95	3.97	3.84	(Fe 2.87)		
Group B - Cast Base Metal Alloys																	
Vitallium	NRC-1(W7588)	AL1	Supplier	.21					28.72(in Co)		63.81	5.89					
		AL1	Laboratory	.25			.022		27.43								
Vitallium	NRC-1	GE1	Laboratory				.012										
6059	NRC-1	AL2	Supplier	.45					24.90		33.02	5.44					

(1) Analyses designated "Supplier" were reported by the producer. Those designated "Laboratory" were made by the Rustless Research Laboratory on the material indicated using standard methods of sampling.

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APPENDIX II - Table 3

Data on Welding Rod and Electrodes

I - Source of Material

Grade	Size	Material	Source of Supply	Heat Number	Laboratory Identification
Type 316	1/8"Dia.	Bare Cold Drawn Wire-Coils	Rustless Iron and Steel Corporation	34683	RS2
N155	1/8"Dia.	Bare Cold Drawn Wire-Coils	Universal-Cyclops Steel Corporation	A11642	UC2
Type 316	1/8"Size	Flux Coated 14" Electrodes	Rustless Iron and Steel Corporation	34683	RX123-C
N155	1/8"Size	Flux Coated 14" Electrodes	Universal-Cyclops Steel Corporation	A11642	RX123-F

II - Chemical Composition (1)

Grade	Material	Lab No.	Analyst	C	Mn	P	S	Si	Cr	Ni	Co	Mo	W	Cb	N
Type 316	1/8" Submerged-Melt Rod	RS2	Supplier	.065	1.59	.026	.009	.37	17.52	12.39		2.19			
			Laboratory	.072	1.71	.026	.011	.41	17.45	12.42		2.17			
N155	1/8" Submerged-Melt Rod	UC2	Supplier	.15	1.45	.011	.014	.50	21.06	19.79	20.25	3.14	1.68	1.13	
			Laboratory	.172	1.39	.015	.012	.49	21.14	19.81	18.35	2.94	2.06	.95	
Type 316	Deposited Weld Metal	RX123-C	Laboratory	.070	1.35	.031	.010	.34	17.64	12.71		2.28			
N155	Deposited Weld Metal	RX123-F	Laboratory	.133	1.47	.012	.009	.58	21.05	18.73	18.73	3.01	2.28	1.01	.127

III - All-Weld-Metal Tensile Properties of Manual-Arc Welds (2)

Grade	Electrode Size	Core Wire Heat No.	Flux Coating Lab No.	Ult. Tens. Str. PSI	.2% Yld. Str. PSI	Elong. % in 2"	Remarks
Type 316	1/8"	34683	RX123-C	82,750	58,000	41.5	No bead cracking
				82,300	56,500	40.5	No bead cracking
N155	1/8"	A11642	RX123-F	109,000	74,750	18.0	Both tested specimens had a few small tears in the surface and a small slag inclusion in the fracture
				109,800	72,200	20.5	

(1) Analyses of weld metal deposited by manual-arc process were made with chips from a standard-type weld pad.

(2) Tensile properties were determined with a standard .505" diameter tensile specimen machined longitudinally from a single-V restrained butt-joint in mild steel plate.

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APPENDIX II - Table 4

Submerged-Melt Welded Bead-on-Plate Tests

Base Metal	Filler Metal	Specimen Number	Penetration of Weld Bead (1)	Initial Base Metal Temp.	Defects Detected by Macro Etch and Metallographic Examination
Hastelloy "B"	Type 316	U-4	Shallow	75°F.	None
		U-3	Shallow	600°F.	None
		U-20	Deep	75°F.	None
		U-21	Deep	600°F.	None
N155	N155	U-33	Shallow	75°F.	Two small cracks in heat-affected-zone which extended into the weld metal.
		U-34	Shallow	600°F.	None
		U-35	Deep	75°F.	None
		U-43	Deep	600°F.	None
Timken 16-25-6	Type 316	U-1	Shallow	75°F.	None
		U-2	Shallow	600°F.	None
		U-25	Deep	75°F.	None
		U-26	Deep	600°F.	None
Uniloy 19-9 DL	Type 316	U-7	Shallow	75°F.	Five small intergranular cracks in weld metal.
		U-9	Shallow	600°F.	None
		U-32	Deep	75°F.	None
		U-31	Deep	600°F.	None
S816	Type 316	U-8	Shallow	75°F.	None
		U-10	Shallow	600°F.	None
		U-23	Deep	75°F.	None
		U-24	Deep	600°F.	None
Vitallium	Type 316	U-17	Shallow	75°F.	One large intergranular crack in weld metal. One small intergranular crack in heat-affected-zone of base metal which extends into weld metal.
		U-18	Shallow	600°F.	One medium intergranular crack in weld metal.
		U-28	Deep	75°F.	Two intergranular cracks in heat-affected-zone of base metal which extend into weld metal.
		U-27	Deep	600°F.	Numerous intergranular cracks in heat-affected-zone of base metal which extend into weld metal.
6059	Type 316	U-19	Shallow	75°F.	One large transgranular crack in weld metal.
		U-29	Deep	600°F.	Numerous intergranular weld metal cracks.
		U-30	Deep	600°F.	Numerous intergranular weld metal cracks.

(1) The operating conditions used to achieve shallow and deep bead penetration are given in the section on Test Procedure

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APPENDIX II - Table 5

Manual Arc-Welded Bead-on-Plate Tests

Base Metal	Filler Metal	Specimen Number	Initial Base Metal Temp.	Defects Detected by Macro Etch and Metallographic Examination
Hastelloy "B"	Type 316	M-10 M-11	75°F. 600°F.	None None
N155	N155	M-5 M-6	75°F. 600°F.	None None
Timken 16-25-6	Type 316	M-13 M-14	75°F. 600°F.	None None
Uniloy 19-9 DL	Type 316	M-3 M-4	75°F. 600°F.	None None
S816	Type 316	M-15 M-16	75°F. 600°F.	None None
Vitallium	Type 316	M-18 M-20	75°F. 600°F.	None One small intergranular crack in base metal heat-affected-zone which extends into the weld metal.
6059	Type 316	M-23	75°F.	One small intergranular crack in base metal heat-affected-zone.

APPENDIX II - Table 6

Restrained Butt-Joint Weld Tests

Submerged-Melt and Manual-Arc Processes

Base Metal	Filler Metal	Specimen Number(1)	Defects Detected by Macro Etch and Metallographic Examination
Hastelloy "B"	Type 316	U-16	None
		M-9	Few very small intergranular cracks found in one top weld bead.
N155	N155	M-8	Few small intergranular cracks found in weld metal.
Timken 16-25-6	Type 316	U-16	None
		M-17	One small crack in weld metal.
Uniloy 19-9 DL	Type 316	U-6	Several large vertical cracks found through beads at ends of weld joints. A number of other small cracks also present in weld metal.
		M-7	A number of medium cracks present in weld metal.
S816	Type 316	U-14	None
		M-21	Numerous cracks present in weld metal. Intragranular cracking found in heat-affected-zone of base metal. See Figure 12.
Vitallium	Type 316	U-15	Several cracks present in weld metal. Numerous intergranular cracks found in heat-affected-zone of base metal which extended into the weld metal.
		M-12	Numerous weld metal cracks present.
6059	Type 316	M-22	A number of medium intergranular cracks present in the weld metal. One medium intergranular crack found in heat-affected-zone of the base metal.

(1) The test specimen no. indicates the welding process; the prefix "U" signifies submerged-melt welding, the prefix "M" signifies manual-arc welding. All test plates were welded with the base metal initially at room temperature (approximately 75°F.) and a maximum interpass temperature of 150°F.

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APPENDIX II - Table 7

Results of Mechanical Tests on Restrained Butt-Joint Welds

Submerged-Melt and Manual-Arc Processes

			Tensile Test Results (1)				Bend Test Results (2)	
Base Metal	Filler Metal	Specimen Number	Ult. Tens. Str. PSI	Elong. % in 2"	Red. in Area %	Location of Fracture	Bend Angle	Description of Fracture
Hastelloy	Type 316	U-16	107,000	8.5	25.1	In center of weld metal	25°	Thru center of weld metal
		M-9	82,400	14.0	51.8	In center of weld metal	34°	Along weld-base interface
N155	N155	M-8	115,100	7.5	27.0	In center of weld metal	25°	Started in center of weld metal and traversed to interface
Timken 16-25-6	Type 316	U-16	94,200	16.0	47.6	In center of weld metal	58°	DID NOT FAIL - Further bending halted by jig.
		M-17	Premature failure of specimen in grip				42°	Thru center of weld metal
Unilloy 19-9 DL	Type 316	U-6	100,400	17.0	43.7	In center of weld metal	43°	Along weld-base interface
		M-7	93,100	7.5	27.5	Started in Base Metal Traversed to weld metal	19°	Thru base metal adjacent to weld joint
S816	Type 316	U-14	107,700	5.0	23.9	In center of weld metal	21°	Thru center of weld metal
		M-21	100,000	9.0	43.3	In center of weld metal	25°	Along weld-base interface
Vitallium	Type 316	U-15	(Not Made)				9°	Along weld-base interface
		M-18	(Not Made)				54°	Started in weld metal and traversed to base metal
6059	Type 316	M-22	(Not Made)				0°	Thru base metal

(1) Tensile test specimen ½" x 1" was taken transverse to longitudinal axis of weld joint. Included weld metal and some plate metal on either side of joint.

(2) Bend test specimen 7/8" wide was taken transverse to longitudinal axis of weld joint. Top of weld joint was ground flush with surface. Specimen bent as free-bend test by supporting each end in a jig die and forcing plunger member on weld root with a hydraulic machine.

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APPENDIX II - Table 8

Program of Wheel-and-Bucket Design Test Specimens using Submerged-Melt and Manual-Arc Welding Processes

Wheel Metal	Bucket Metal	Weld Filler Metal	Welding Preheat Temperature
Section I - Influence of Preheat Temperature			
Timken 16-25-6	S816	Type 316	(1) 75°F.
Timken 16-25-6	S816	Type 316	(2) 300°F.
Timken 16-25-6	S816	Type 316	(3) 600°F.
Timken 16-25-6	S816	Type 316	(4) 1000°F.
Section II - Weldability of Eight Bucket Alloys			
Timken 16-25-6	(1) Hastelloy "B"	Type 316	600°F.
Timken 16-25-6	(2) S816	Type 316	600°F.
Timken 16-25-6	(3) Vitallium (Austenal)	Type 316	600°F.
Timken 16-25-6	(4) Vitallium (General Electric)	Type 316	600°F.
Timken 16-25-6	(5) Vitallium (Haynes Stellite)	Type 316	600°F.
Timken 16-25-6	(6) 6059	Type 316	600°F.
Timken 16-25-6	(7) 422-19	Type 316	600°F.
Timken 16-25-6	(8) X40	Type 316	600°F.
Section III - Weldability of Two Alloys for Cold Type Wheels			
(1) Timken 16-25-6	The tests having best and poorest performing bucket metals will be selected from Section II.	Type 316	600°F.
(2) Uniloy 19-9 DL	Use best and poorest alloys from Section II.	Type 316	600°F.
Section IV - Weldability of Three Alloy Combinations for Hot Type Wheels			
(1) S816	S816	S816	600°F.
(2) S816	S816	Hastelloy "B"	600°F.
(3) S816	X40	Hastelloy "B"	600°F.
Section V - Weldability of Two Weld Filler Metals			
Timken 16-25-6	S816	(1) Type 316	600°F.
Timken 16-25-6	S816	(2) Hastelloy "B"	600°F.
Section VI - Weldability of Two Alloys for Both the Buckets and Wheels of Gas Turbines			
N155	N155	N155	600°F.
S590	S590	S590	600°F.

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APPENDIX II - Table 9

Interbucket Notch-Extension Measurements in Wheel-and-Bucket Design Tests

Welded by Submerged-Melt Process

Wheel Metal	Bucket Metal	Filler Metal	Specimen No.	Shape of Weld Deposit	Data on Junction Extension: Total Inches in Top Bead (7 Junctions)	Total Inches in Bottom Bead (7 Junctions)	Total Inches in Test Plate	Average Extension per Junction - Inches
Section I - Influence of Preheat Temperature								
Timken	S816	Type 316 (75°F)	U-53	Narrow	.422	.360	.782	.056
		(300°F)	U-54	Narrow	.086	.438	.524	.037
		(600°F)	U-36	Wide	1.200	1.700	2.900	.207
		(600°F)	U-38	Wide	1.310	1.108	2.418	.173
		(600°F)	U-58	Narrow	.200	.203	.403	.029
Section II - Weldability of Bucket Alloys								
Timken	Hastelloy	Type 316	U-37	Wide	.031	.244	.275	.020
			U-55	Narrow	.078	.062	.140	.010
			U-57	Narrow	.164	.125	.289	.021
Timken	S816	Type 316	U-36	Wide	1.200	1.700	2.900	.207
			U-38	Wide	1.310	1.108	2.418	.173
			U-58	Narrow	.200	.203	.403	.029
Timken	Vitallium (AE3)	Type 316	U-43	Narrow	.164	.211	.375	.027
			U-49	See Fig. 16	.281	.686	.967	.069
Timken	Vitallium (GE3)	Type 316	U-44	Narrow	.304	.036	.340	.024
			U-51	Narrow	.438	.484	.922	.066
			U-59	Narrow	.609	.375	.984	.070
Timken	Vitallium (HS5)	Type 316	U-45	T-Wide B-Narrow	.484	.156	.640	.046
			U-52	Narrow	.390	.340	.730	.052

APPENDIX II - Table 9 (Cont.)

Interbucket Notch-Extension Measurements in Wheel-and-Bucket Design Tests

Welded by Submerged-Melt Process

Wheel Metal	Bucket Metal	Filler Metal	Specimen No.	Shape of Weld Deposit	Data on Junction Extension: Total Inches in Top Bead (7 Junctions)	Total Inches in Bottom Bead (7 Junctions)	Total Inches in Test Plate	Average Extension per Junction - Inches
Section II - Weldability of Bucket Alloys (Cont.)								
Timken	6059	Type 316	U-46	Wide	.312	.343	.655	.047
			U-50	Narrow	.234	.367	.601	.043
Section VI - Weldability of Alloys for Both Buckets and Wheels of Gas Turbines								
N155	N155	N155	U-42	Wide	.343	.359	.702	.050
			U-48	Wide	.117	.265	.382	.027
			U-56	Narrow	.343	.219	.562	.040
Miscellaneous Tests								
Timken	Timken	Type 316	U-41	Wide	.016	.031	.047	[illegible]
Unilloy 19-9 DL	S816	Type 316	U-39	Narrow	.484	.582	1.066	[illegible]
			U-40	Wide	.920	.468	1.388	[illegible]

APPENDIX II - Table 10

Interbucket Notch-Extension Measurements in Wheel-and-Bucket Design Tests

Welded by Manual-Arc Process

				Data on Junction Extension			
Wheel Metal	Bucket Metal	Filler Metal	Specimen No.	Total Inches in Top Bead (7 Junctions)	Total Inches in Bottom Bead (7 Junctions)	Total Inches in Test Plate	Average Extension per Junction - Inches
Section II - Weldability of Bucket Alloys							
Timken	Vitallium (AL3)	Type 316	M-27 M-30	.072 .312	.117 .250	.189 .562	.014 .040
Timken	Vitallium (GE3)	Type 316	M-28 M-31	.140 .266	.086 .359	.226 .625	.015 .046
Timken	Vitallium (HS5)	Type 316	M-29	.375	.266	.641	.046

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ABSTRACT

Study was made of the welding characteristics of heat-resisting alloys employed in turbosuperchargers, jet engines, and gas turbine wheels. Welds in five wrought alloys and two cast materials were subjected to the bead-on-plate test, restrained butt-joint test, and a special wheel-and-bucket type of test. Three types of cracking found to be prevalent were weld metal cracking, heat-affected-zone cracking, and cracks propagating from interbucket junctions. In general, Hastalloy "B" and Timken 16-25-6 alloys appeared to be the least susceptible to welding defects.

T-2, HQ., AIR MATERIEL COMMAND — AIR TECHNICAL INDEX — WRIGHT FIELD, OHIO, USAAF

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